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ENSURE THE STABILITY OF THE WATER RETENTION PLATES OF HYDRAULIC STRUCTURES

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ABSTRACT

In this article are presented the results of experiments on determining averaged and pulsating loads from flow on fastening plates using point and total load sensors. An assessment of pulsation pressures and calculations of hydrodynamic loads on the fastening elements of the downstream of a three-span spillway with an expanding water well, operating in conditions of spatial conjugation of the pools and the presence of three rows of dampers, were carried out. Are analyzed the results of model hydrodynamic studies of short-span culvert structures, which were not sufficiently taken into account during the design, construction and operation of the Shamkir hydroelectric complex on the Kura River. It is noted that on the water basin and apron, when the spillway is operating, both with all culvert openings and with an incomplete front, a wide range of energy-carrying frequencies appears in the amplitude-frequency spectra of pressure and load pulsations. In this case, there is a natural decrease in the role of high-frequency oscillations as one moves away from the area of intense pressure pulsation at the water body and the disappearance of predominant frequencies with a transition from high-frequency spectra at individual points to low-frequency spectra of loads on entire slabs. Ways to optimize the design of fastening plates are proposed. An assessment is made of the possibility of using known methods for finding the total hydrodynamic loads to calculate the stability and strength of the slabs for fastening the water breaker and the apron of tubular-type reclamation spillway structures in relation to the spillway end device of the Shamkir hydroelectric power station in Azerbaijan during its renovation.

Keywords: Fastening plates, Averaged pulsation loads, Pressure pulsation spectra, Drainage holes.

INTRODUCTION

For normal trouble-free operation of both large, medium and small spillway hydraulic structures, it is important to have well-designed and high-quality tailwater devices (elements of the water basin, apron, end device, etc.), ensuring a favorable mode of connecting the pools, preventing disrupted flows and dangerous washouts in the outlet channel (Rozanov, 1984). These devices must be stable and durable when exposed to flow and not be subject to unacceptable damage due to dynamic wave action, cavitation and a number of other factors (Abidov and all, 2020). There are more than 45 thousand large dams operating in the world today, the average age of which is approximately 37 years, and in Russia it is approaching 50 years.

Destructions at such waterworks due to failure of the spillway structure account for more than 30% (Volkov and Chernykh, 2019). Timely repair and reconstruction significantly reduce the risk of an accident at a hydroelectric power station and its consequences (Chernykh and Burlachenko, 2022). It should be taken into account that many issues of hydraulics and hydrodynamics of the downstream of spillway structures have been studied or not taken into account fully enough during the design (Chernykh and Komelkov, 1983). This was one of the reasons that some spillway structures operated unsatisfactorily immediately after commissioning and failed before reaching their intended service life or required significant repairs (Burlachenko et al. Brakeni, 2023). Currently, the main activities of hydraulic engineers are focused on improving existing hydraulic structures: reconstruction, modernization and optimization of the functioning of all hydraulic structures (Volkov and Chernykh, 2012).

It should be taken into account that the destruction of fastening elements and vibration of the slabs are often caused by pulsating loads acting in the downstream of the waterworks on the water outlet and apron. In addition, when vibration is transmitted to the ground, various physical and mechanical changes may occur in it, which will lead to settlement of the slabs, and then to deformation of the entire fastening or transmission of vibrations and reshaping of the soil under the dam and in the coastal zone of influence of the operating modes of the hydraulic system. Therefore, in the article, using the example of the Shamkir hydroelectric complex, the main attention is paid to studying the effect of hydrodynamic loads on dampers and the bottom of an expanding water body to optimize the design solution of the downstream elements during the renovation of such spillway structures.

The Shamkir waterworks complex (1975-1983) is located on the river Kure in Azerbaijan and is part of the Kurey hydroelectric power station cascade. This is the second largest hydroelectric power station in northwestern Azerbaijan. The reservoir provides irrigation water to 46,000 hectares (110,000 acres) of land. The hydroelectric complex structures include earth dams, a spillway, a hydroelectric power station building with a water intake, two turbines and turbine water pipelines with a capacity of 380 MW, and an irrigation water intake. The projected average annual electricity generation is 810 million kWh (Fig.1).

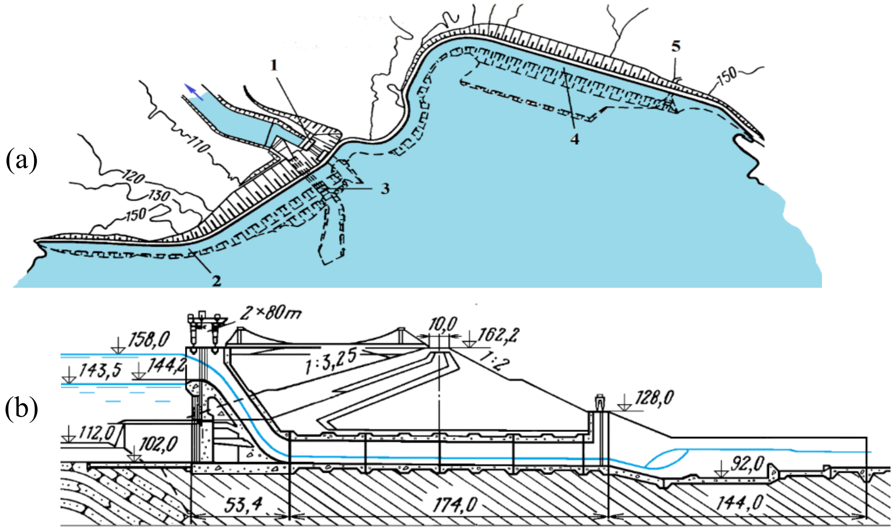


Figure 1: Plan of the Shamkir hydroelectric complex. (a) and longitudinal section along the operational spillway (b)

1 – hydroelectric power station; 2 – channel earthen dam; 3 – spillway; 4 – floodplain earthen dam; 5 – water intake

The area of the reservoir at normal retaining level is 116 km². A channel earth dam with an inclined loam core has a crest length of 1800 m and a maximum height of 70 m. A floodplain dam with a loamy screen has a height of 40 m and a crest length of 1700 m. The construction and operational spillway, located in the body of the channel dam, includes: entrance head with three spans 7.5 m wide; bottom pipe galleries at the base of the dam, 160 m long; output head with dampers; outlet channel. The spillway transit tract is divided by two 1.5 m thick bulls into three galleries, each 8.3 m wide. Since 2003, the waterworks have been in disrepair. Due to the corrosion of concrete, the appearance of large cracks, the destruction of the protective layer of concrete of the three-point underground water conduit at a length of 160 m, the exposure of reinforcement, the destruction of the concrete fastening of the waterway section and erosion behind the apron, as well as a strong leakage of water through the concrete and contact sections could at some point lead to an emergency situation at a waterworks. The soil retaining structures were also in disrepair. Based on a general analysis given by international experts at the beginning of the twentieth century, the Shamkir hydroelectric complex was classified as the highest risk. In this regard, starting from 2021, work began on the repair and renovation of the main hydraulic structures of the Shamkir hydroelectric complex (Fig. 2). At the same time, it was planned to carry out repair and restoration work on the hydraulic units of the Shamkir hydroelectric power station.

a)

b)

Figure 2: Reconstruction of the concrete fastening behind the three-point spillway of the Shamkirsky hydroelectric complex, March 2021: a – view from the downstream side; b – renovation of the water treatment area.

METHODS

A model installation for assessing hydrodynamic loads on the fastening elements of the downstream of the culvert was made of stone and wood on a linear scale of 1:50 in relation to the conditions of the three-span spillway of the Shamkir hydroelectric complex with the following parameters: maximum flow Q = 2980 m^3/s; pressure relative to the outlet section of the pipe $H = 4.92d_1$, where d_1 = 12 m – height of the rectangular gallery; difference $p = 1.33d_1$; relative specific energy of the flow leaving the pipes $(E_1+p)/h_1$ = at 7.2 to 9.6; $E_1 = h_1 + v^2{}_1/2g$; h_1 and v_1 – depth and speed at the exit from the gallery; g = 9.81 m/s^2; depth in the outlet channel $h_2 = (0.63...1.08)d_1$; flooding of the outlet section $\varepsilon_n = (h_1 - p)/h_2$ = at 1.9 to 2.7 (Rozanov, 1984). The simulation was carried out according to the criterion of gravitational similarity. At the same time, the model provided Reynolds numbers that were in the self-similar zone (Re = at 20000 to75000). The damping system was selected in the research sector of the Hydroproject Institute and consisted of three rows of jagged thresholds on an expanding water well with an angle θ = 240 (Fig. 3). Behind the last row of dampers, the axis of the structure turned to $32^{0}47^{I}$. Features of the interface section: high Froude number in the compressed section (up to 15 to60); a water well that expands in plan; special type dampers; rotation of the outlet channel; the possibility of a spatial jump, etc., made it difficult to use analogues for calculating the quasi-static stability of fastening elements.

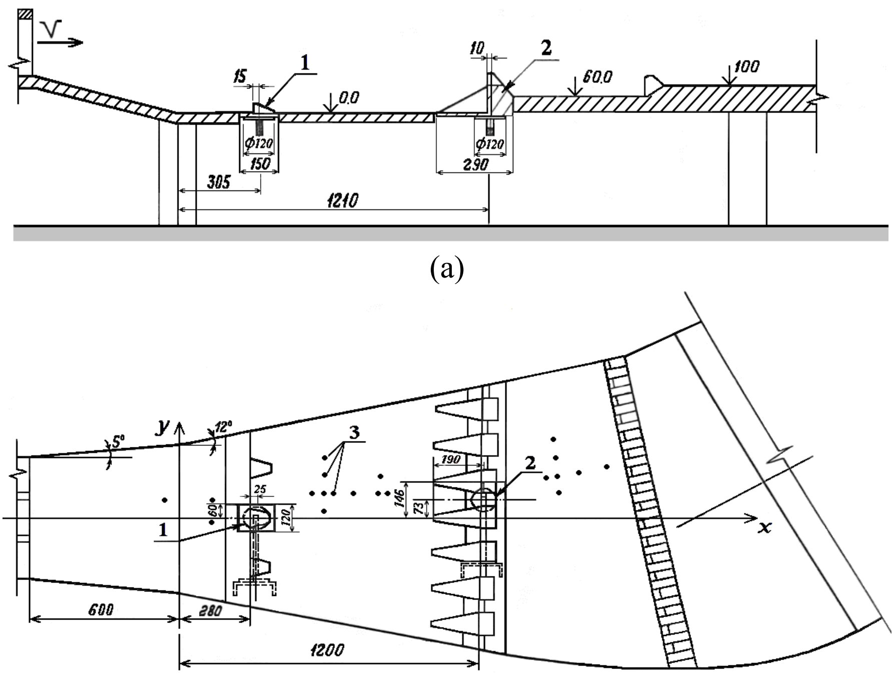


Figure 3: Installation diagram of sensor dampers (1) and point sensors (2) on the spillway model of the Shamkir hydroelectric complex: a) longitudinal section along the axis of the outlet head; b) plan of the exit section

The dynamic research program included conducting experiments to determine the hydrodynamic loads on the water break and apron slabs, assessing their stability, and optimizing the thickness and design of the fastening slabs. During the experiments, the static component of the pressure on the fastening elements was determined by piezometer, and the average velocities were determined by a microspinner and a Pitot tube. The pulsation component of pressure was measured by 20-point inductive pressure sensors with a receiving membrane with a diameter of 6 mm and a natural frequency of 2 kHz. The total hydrodynamic pressure, including on fragments of gear dampers, was recorded using a cantilever-type platform sensor plate, which allows recording longitudinal and vertical loads and has a natural vibration frequency in water of 40...60 Hz (Rozanov, 1984).

For dynamic studies, 3 operating modes of the structure were selected: 1 – skipping the maximum design flow – Q = 2900 m^3/s with three completely open spans, $(E_1+p)/h_1$ = 9.6, ε_n = 2.7; 2 – with only the leftmost span open and Q = 790 m^3/s, $(E_1 + p)/h_1$ = 7.2 and ε_n = 2.9; 3 – flow rate Q = 790 m^3/s through only one middle completely open span, $(E_1 + p)/h_1$ = 7.2, ε_n = 2.9. The average pressure on the mounting plates from above for each hydraulic mode was determined by the height of the piezometric line above the mark of the bottom of the water well and apron.

RESULTS AND DISCUSSION

To select the optimal design and thickness of reinforced concrete fastening (including taking into account the load in its sub-slab cavity, the presence and location of drainage wells) with modern methodologies (Chernykh and Burlachenko, 2023; Sidorova, 2022), the external influence of the flow on the slab $\tilde{P}(t)$ is first of all specified as average load on the slab from above $<\tilde{P}(t)> = \bar{P}$:

$$p(t) = \overline{p} + p(t) \quad (1)$$

In this case, in a stationary mode, the pulsating pressure $P(t)$ is represented as a function of the spectral density $Sp(\omega)$, determined experimentally or theoretically (Lyakher, 1968; Lyakher and Chernykh, 1980).

As a result of the experiments, a number of patterns were identified in the distribution of the averaged $\bar{P}_i$ and pulsation components of pressure $P(t) = P_i$ at individual points along the area of attachment of the water jet and apron. The average pressure along the fastening of the outlet bell head changes most sharply when all three openings of the Shamkir waterworks spillway are operating at maximum flow (mode 1). The first damper, consisting of a springboard boss and three teeth, promotes bending of the jet and an increase in pressure in the area up to the front face of the tooth $\bar{P}_i = 4\gamma h_1$. Behind the teeth, the pressure drops, with the greatest pressure deficit related to the velocity pressure at the exit from the gallery $\beta = |(\gamma h_2 - \bar{P}_i)/(v^2_1/2g)| = |\Delta P_{cp}/\gamma(v^2_1/2g|$ is 0.23. At the water basin, areas of decreased pressure extend to the first third of the slab of the second row, and then the pressure increases and practically corresponds to hydrostatic pressure (Fig. 4). When a structure with a closed middle span operates, the pressure is redistributed over the surface of the water basin and its maximum decrease (β = 0.15) is observed along the axis of the faulty flow in the zone of jet stall. When the structure operates with two galleries (mode 3), the slabs of the apron and slopes are more loaded than the structure with three galleries (mode 1) (in the area of closed holes β increases 4 times). Behind the dampers, - this is where pressure drops appear, while throughout the entire section of the tailwater there is only a redistribution of the average pressure over the anchorage area.

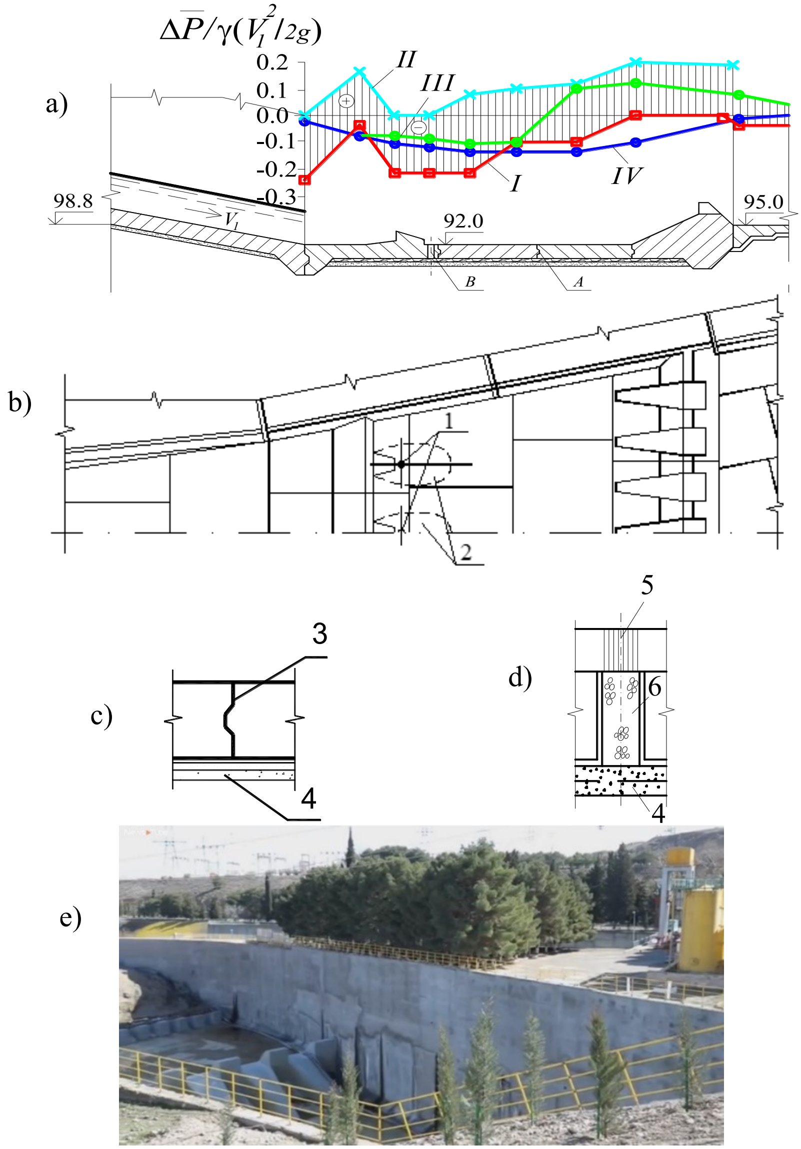


Figure 4: Scheme of quasi-static loading and the proposed structural elements of the fastening slabs of the water outlet section of the Shamkir hydroelectric complex:

a - longitudinal section along the water well; b – plan of the water basin with cutting into slabs; c – node A; d – node B; e – photo of the progress of work on the renovation of the end section of the spillway;

1 – drainage wells; 2 – separation area behind the absorber; 3 – painting with a waterproofing compound; 4 – layers of reverse filter or porous concrete with gravel; 5 – tubes or holes with a *diameter of 0.1...0.0 m; I, II – diagram P when all three galleries are operating in the absence or presence of drainage wells (mode 1); III – only one leftmost gallery works (mode 3); IV – one middle gallery works (mode 2)*

As a result of the experiments, areas with the highest intensity of pressure pulsation, characterized by the values of the pulsation standard *P'*, were identified. (Sidorova, 2022). It has been established that on an expanding water body of a spillway operating with all galleries (mode 1), the pulsation intensity is greatest behind each of the disturbance sources - the corresponding row of dampers. This is explained by the presence of separation regions behind them with significant velocity pulsations and instability of the high-frequency pressure component. Thus, the relatively high intensity of pulsation ($P' = 0.085.\ \gamma v^2_1/2g$) behind the damper of the first row in this operating mode of the spillway is associated mainly with the effects of spatial flow around the teeth (Fig. 5), and the distribution of the intensity of pressure pulsation only in the area up to the first damper corresponds to the intensity distribution under a flat jump (Lyakher, Chernykh 1980). Behind the second row of dampers, the pulsation intensity is small and amounts to $0.018\gamma v^2_1/2g$. When the spillway operates with one middle span (mode 3), a slight increase in pressure pulsation is observed on the slabs of the first row. Behind the first jagged threshold, the pulsation standard across flow increases from $0.01\gamma v^2_1/2g$ at a distance from the outlet section of the gallery $l = 0.12d_1$ to $0.114\gamma(v^2_1/2g)$ at $l = 1.12d_1$. In general, when the structure operates with an incomplete front, the values of the pressure pulsation standard on the slabs of the second and third row are less than when operating structures with all openings.

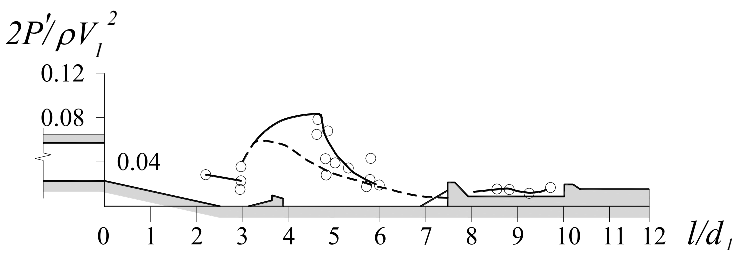


Figure 5: Change in the relative standard of pressure pulsation $2P'/\rho v_1^2 = P'/\gamma v^2_1/2g$ (where $\rho = \gamma/g$ is the density of water) at the points of attachment of the bottom of the bell section behind the spillway when all three galleries are operating (mode 1)

The uniqueness of the damping scheme and the smooth expansion of the flow leads to the fact that in the water basin with the dampers under consideration, even when all the pipes are operating, a spatial regime is observed. Averaged and pulsating velocities are unevenly distributed across the width and depth of the flow. In the absence of a surface roller, in some modes the velocity gradients in depth change significantly, so the lateral interface zones located in the interpipe areas and in places adjacent to the vertical walls of the socket have a strong influence.

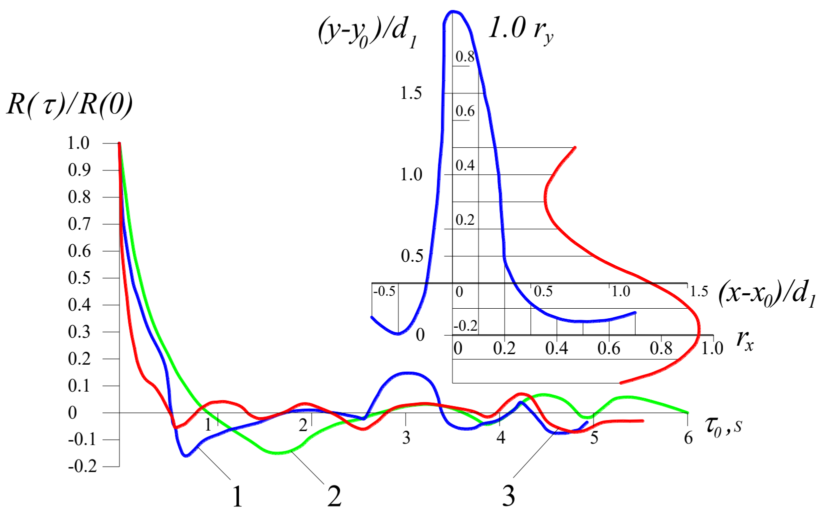
In areas with maximum standard values, pressure pulsation spectra have predominant frequencies. In the process of processing experimental data, it was found that for a preliminary assessment of the frequencies of the maximum of the amplitude-frequency spectrum on the expanding water body behind the first row absorbers, the known dependence for the drum frequency above the jet $\varpi_в$ can be used (Chernykh and Burlachenko, 2023; Chernykh and al, 2023).

$$\varpi_b = 2V / (h_2 - h_1) \approx (at0.8to0.5) \times \frac{V_1}{0.5} \times L_r \tag{2}$$

where V is the vertical component of the speed in a jump; h_1 and h_2 are the flow depths at the beginning and end of the jump, respectively, in the area under consideration; L_r– roller length.

The predominant frequency of the high-frequency component of oscillations $\varpi_n = 2\pi/\tau_o$ according to the autocorrelation functions $R(\tau)$ was identified by the shortest time interval τo at which the value of $R(\tau)$ became equal to 0 or crossed the approximating curve of the low-frequency oscillation component. The value of ϖ_p in front of the first row of absorbers is about 2.4...3.7 Hz, and behind the second row absorbers it is no more than at 0.3 to 0.8 Hz. When moving to the surface mode and approaching the absorbers of the second row, low-frequency components are already energy-carrying, due to which dispersion is formed. In this case, the value of ϖ_n is no more than 0.1 Hz. Since pressure fluctuations in the outlet channel and on slopes occur mainly due to surface roughness, an even lower frequency component can be traced in the autocorrelation functions, which also determines the shape of the spectrum. A comparison of autocorrelation functions and longitudinal correlations made it possible to establish that the speed of disturbance drift, depending on the size of the drifted vortices, for the transition from frequency spectra to longitudinal ones can be taken for the gear threshold equal to ~ 0.8, and for the exit section of the bell at 0.18 to 0.04 from the local average speed currents. This is slightly lower than indicated in (Chernykh and al, 2023) for the end of the jump.

In general, it can be noted that on a water body with dampers of the scheme under consideration for all modes, the spatial correlation between pulsations at different points of the first row fastening slabs is extremely high: at a distance of $0.42d_1$ across the flow, the correlation coefficient is equal to $r = R(\tau)/R(0) = 0.9$, and at a distance of $0.83d_1$ along the current $r = 0.6$ (Fig. 6). In the region of jet incidence, the longitudinal correlation sharply decreases, turning negative over a section of approximately $0.3d_1$ length. The cross-sectional correlation decreases less sharply here. Almost all autocorrelation functions show a weakly damped low-frequency component, apparently associated with the free surface disturbance generated by the jet.



a) b)

Figure 6: a) Spatial correlation; b) types of autocorrelation functions of pressure pulsations at different points along the axis of the bottom of the water well. 1 – in front of the first row absorber; 2 – in the middle of the water hole, between the first and second rows of dampers; 3 – behind the second row of dampers

Spectral density functions indicate a wide range of pressure fluctuations (Chernykh, 1982). The largest contribution to the oscillation dispersion is provided by the component with a predominant frequency of 2.0...2.5 1/s. Below the first absorber, even at closely located points, the spectra and pulsation standards vary greatly. When the spillway operates with a medium span (mode 3), even lower frequencies become energy-carrying, which is mainly due to a decrease in average flow velocities (Chernykh and Burlachenko, 2022).

At the outlet head there are six rows of downstream fastening slabs with the studied design of damping devices: on the water breaker there are 4 rows across the flow and on the apron there are 2 rows with dimensions of 2.4h_1x2.4h_1, 2.0h_1x2.4h_1 and 3.0h_1x3.0h_1, respectively. The results of calculating pulsation loads (P'_o - the standard of pulsation of a uniformly distributed load, causing an action on the slab of the same force as the actual vertical pulsation load) and moments (P'_{om} - the standard of pulsation of a uniformly distributed specific load, causing the action of the same overturning moment, as the actual pulsating load) taking into account spatial correlations between load fluctuations on elementary platforms (L_o = 0.6h_1), are presented in Figure 7. Analysis of the results obtained once again confirms the experimental data on a sharp decrease in load with distance from the beginning of the hydraulic jump.

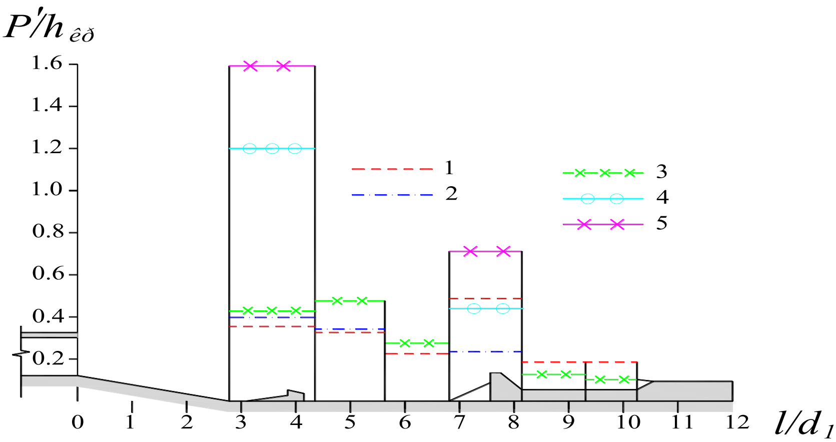


Figure 7: Comparison of specific averaged pulsation loads *P'₀* on the socket bottom fastening plates: 1 - *P'₀* according to data from (Lappo, 1988) for mode 1; 2 and 3 - experimental data during the operation of all three galleries *P'₀* and *P'ₒₘ*; 4 and 5 *P'₀* and *P'ₒₘ* when the structure operates only on the middle span

For the slabs of the first row of fastening together with the absorber of the first row, which experience the greatest pulsation effects, there is a coincidence with the experimental data of G.A. Yuditsky (Larro, 1988) is quite good – less than 12%. In the underlying sections of the water basin and apron, this discrepancy is more significant and reaches 47%, which can be explained by a decrease in the scale of turbulence due to the installation of jagged thresholds and greater flooding compared to the conjugating conditions in the noted works. When the structure operates with only one middle gallery (mode 3), the specific loads on the slabs of the first row increase on average by 1.3 times compared to the operation of the structure along the entire front (mode 1). Calculation according to current recommendations (Recommendations, 1979) in this case gives a significantly underestimated result (by 1.7 times). This indicates the limitation of the application of this methodology in the conditions of the spatial regime of connecting pools with a significant degree of flow expansion. The reason for some discrepancies may also be that the recommendations (Recommendations, 1979) were obtained on the basis of amplitude analysis without taking into account the dynamic nature of the load.

The distribution of pulsating loads measured by the sensor plate and their frequency characteristics indicate that the effect of spatiality on the water basin is reflected the weaker the further the area under consideration is removed from the mixing zones of transit jets behind spreaders of different designs (Rozanov, 1984; Chernykh and Burlachenko, 2022). The appearance of a low-frequency component of oscillations is typical for sections of the water slab adjacent to the vertical walls of the socket, since it is this component that implements the action of the lateral whirlpool regions when energy absorbers are installed on the water slab (Lyakher and Chernykh, 1980).

Spectra of specific weighing loads $S_p(\omega)$ and loads equivalent to the action of an overturning moment relative to the transverse edge of the second row slab $S_M(\omega)$ (Fig. 8). show the effect of transition from point to site using the "frozen" turbulence hypothesis (Lyakher and Khalturina, 1977). The averaging effect leads to a sharp increase in the role of low-frequency pulsations, while the main energy-carrying frequencies are (0.5...1.2)1/s.

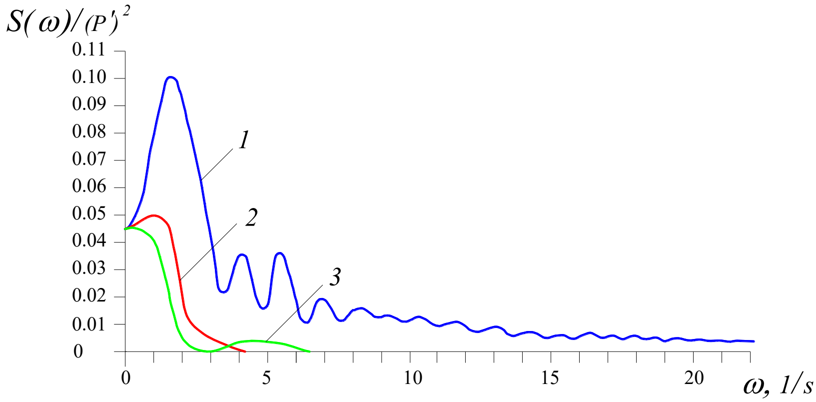


Figure 8: Functions of the spectral density of pressure pulsations and loads on the slabs of the water breaker behind the first row of dampers when the spillway operates in three galleries (mode 1): 1 – $S(\omega)$; 2 – $S_M(\omega)$; 3 – $S_p(\omega)$

As a result of the analysis of the frequency characteristics of load fluctuations, the coefficients of increase in the spacecraft load were obtained K_A, characterized by the ratio of the extreme deviation from the average value to the standard pulsating load that occurs during the design mode T with probability P_0 and characteristic pulsation period τ_o:

$$K_A = \sqrt{2\ln\frac{\tau/\tau_0}{2\ln\left(1/p_o\right)}} \tag{3}$$

$$\tau_o = \pi\sqrt{\frac{\int_o^\infty S_p(\omega)d\omega}{\int_o^\infty \omega^2 S_p(\omega)d\omega}} \tag{4}$$

In the case of design mode 1, when the structure operates in full front with three galleries for $T = 1$ day (in reality $T/\tau_o = 2.2\text{x}10^3$) at $P_0 = 0.95$ (as for a structure of hazard class I) and $\tau_o = 2.87$ s, the value of the coefficient is $K_A = 3.94 \approx 4$.

Thus, to optimize the design of the reinforced concrete fastening and its sub-slab cavity during the renovation of the downstream of the spillway, the method for assessing the vibrations and stability of the fastening slabs has been expanded and tested, making it possible to recommend installing drainage wells immediately behind the first row of dampers, to calculate the stresses in the soil of the filter under the slab with such a design diagram of the water hole arising from the vibration of the slab, and then estimate the magnitude of the separation of the slab from the ground and its minimum possible thickness (Chernykh and al, 2023).

CONCLUSION

Research has shown the possibility of a fairly correct assessment of pulsation loads on the downstream fastening slabs of the three-span tubular spillway of the Shamkir hydroelectric complex according to the well-known methodological instructions of the Scientific Research Sector of the Hydro project (Lyakher Khalturina, 1977) and recommendations (Recommendations, 1979), but only taking into account the peculiarities of changes in hydrodynamic characteristics flow in bell-shaped heads equipped with a mixed circuit of damping devices. It has been revealed that calculations based on them give satisfactory results only when the structure operates along the entire front and with additional clarification of some calculation parameters determined experimentally from the results of model studies. The established patterns are given in the form of calculated graphs in relative values and formulas. A diagram of the quasi-static loading of fastening slabs with an instantaneous pulsating load when assessing their stability should be constructed for an expanding water basin with dampers, using longitudinal and transverse correlations corresponding to spatial turbulence, and on the apron - homogeneous. Behind the jagged threshold in such design solutions for water treatment areas, the expression of the spatiotemporal spectrum can be determined under the assumption of spatially symmetrical turbulence. After determining the total loads and constructing a quasi-static load, the strength and stability of the downstream fastening elements, as well as the choice of the optimal design of the entire system “concrete fastening slabs - water-saturated soil foundation” can be assessed using classical methods (Recommendations, 1979). The implementation of these recommendations should ensure the reliability and durability of the operation of the entire whole Shamkir hydroelectric complex after the finish of its complete reconstruction.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

VOLKOV V. I, CHERNYKH O. N., (2012). Open coastal spillways, Moscow, MGUP, 243 p.

VOLKOV V. I, CHERNYKH O. N., (2019). Safety assessment of spillway structures for earth dams, MGUP, Moscow, 118 p.

ROZANOV N. P. (1984). Spillway downstream devices. Moscow, 269 p.

CHERNYKH O. N., BURLACHENKO A. V. (2022). Ensuring the safety of hydraulics structures of a reclamation waterworks with an earth dam, Moscow, RGAU-MSHA, 172 p.

CHERNYKH O. N., KOMELKOV L. V., (1983). Hydrodynamic loads and stability of river beg protection downstream of hydraulic structures, Abstracts XX Congress IAHR, vol. VII.

BURLACHENKO A. V., CHERNYKH O. N., BRAKENI A. (2023) Operation evaluation of water discharge end sections in the conditions of narrow downthrows, Larhyss Journal, 56, 25-38.

CHERNYKH O. N., BURLACHENKO A. V., BURLACHENKO Y. Y. (2023). Experimental and analytical studies of loads on fastening elements behind the spillways of water bodies of the agro-industrial complex. Prirodoobustrojstvo, No. 4, P. 59‑66.

CHERNYKH O. N., BURLACHENKO A. V., BURLACHENKO Y. Y., (2023). Ensuring the reliability of fastening of plates behind culverts of reclamation systems of the Agro-industrial complex // Prirodoobustrojstvo. No. 5. P. 41-46.

LYAKHER V. M., (1968) Turbulence in hydraulic structures. Moscow: Energy, 297p.

LYAKHER V. M., KHALTURINA N. V. (1977) Dynamic loads on the water break and assessment of fastening stability // Proceedings of coordination meetings on hydraulics engineering. Leningrad: Energy, No. 116. p. 44-55.

LYAKHER V. M., CHERNYKH O. N. (1980) Evaluation of the stability of the downstream fastenings of the spillways // Hydraulic engineering and melioration No. 2, p. 25-30.

LAPPO. D. D. (1988). Hydraulics calculations of spillway Hydraulics structures. Reference manual. Moscow, Energoatomizdat, – 624 p

CHERNYKH O. N. (1982) Spatial-temporal correlations and functions of the spectral density of pressure pulsations on the plates for fastening the downstream of tubular structures // Collection of scientific papers. Hydraulic structures, bases and foundations, engineering structures. – M.: MGMI, p. 158-167.

ABIDOV B., VOKHIDOV O., SHODIEV B., ASHIROV B., SAPAEVA M. (2020). Hydrodynamic loads on a water drain with cavitation quenchers. IOP Conference Series: Materials Science and Engineering. 883. Paper. 012011.

RECOMMENDATIONS (1979)., for determining hydrodynamic loads acting on the slabs of reservoirs and aprons of spillway dams. – L.: VNIIG. – 52 p.

SIDOROVA S. A. (2022) Safety of operation of the fastening plates of the downstream of Hydraulics structures // Prirodoobustrojstvo. No. 1, pp 61-65.